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THE SPONTANEOUS APPEARANCE OF THE POTATO RACE 4 CHARACTER IN CULTURES OF *PHYTOPHTHORA INFESTANS*[1]

M. E. Gallegly and J. J. Eichenmuller[2]

Recent race surveys in several countries have shown that potato race 4 of *Phytophthora infestans* (Mont.) de By. is more prevalent than potato race 0, usually considered to be the "common" field race of the late blight fungus. In Canada, Graham (3) noted that 60 per cent of isolates collected from 9 provinces during 1952 and 1953 contained the race 4 character. A continuation of the Canadian survey by Howatt (5) during 1954-1956 showed that race 4 existed in 70 per cent of 1127 isolates. In the Netherlands, Mastenbroek and de Bruin (7) pointed out that a shifting of races had occurred in trial plots so that in 1953 and 1954 race 4 was found predominantly and race 0 disappeared. It was also noted that this shift occurred in commercial fields "far away" from breeding stations; all isolates from these fields were identified as race 4. Similarly, Doling (2) found that race 4 was the predominant race on commercial varieties in Northern Ireland.

The frequency of appearance of the race 4 character in isolates from potato and tomato plants in the United States and other countries was noted by the senior author (8, 10) in race comparison studies. Also, the race 4 character was found to be present in certain isolates reprortedly not having the ability to attack R_4 plants and in isolates taken from commercial tomato fields distantly removed from potato breeding plots. As an example, it was noted that isolate S-B[1], received as race 1 severely infected recessive and R_1 plants but in addition produced a few lesions on R_4 and R_1R_4 plants. It was postulated (8) that certain isolates were either changing in culture to become pathogenic on R_4 plants or that these isolates were mechanical mixtures involving race 4. Since the isolates used in the studies noted above were mass field isolates, it was desirable to study the race characters in a number of single-sporangium and -zoospore isolates in an effort to explain the presence of race 4 in certain cultures and the recently noted abundance of race 4 in nature.

Materials and Methods

The isolates of *P. infestans* used are described in the experimental results. Only single sporangium cultures were made from the first 5 isolates studied. In the beginning it was assumed that the apparent race mixtures could be separated into their component parts if enough single sporangium cultures were made. It soon became evident that it would be desirable to work with cultures theoretically derived from a single haploid nucleus; thus studies with single zoospore cultures were carried out with the last 5 isolates.

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Single zoospores were picked with the aid of a micromanipulator and a micropipette. Small drops of a dilute zoospore suspension were placed on a cover slip and examined microscopically to make sure that the droplet contained only one zoospore. The cover slip was discarded if more than one zoospore was present. Cover slips containing single zoospores were placed between Irish Cobbler tuber halves which were bound together, wrapped in a moist paper towel and incubated in a humidity chamber held at 20° C. After infection was evident, isolations to agar were made directly from the tubers or from leaves of plants inoculated with sporangia produced on the tubers.

Single-sporangium cultures were made by picking sporangia from the surface of water agar with an enlarged needle eye and placing them in tubers as described above or by placing them directly in frozen-lima bean agar (blended frozen lima beans, 200 gm; agar, 17 gm; distilled water to make 1,000 ml.)

The differential hosts used for race identification and their genotypes were as follows: Irish Cobbler (recessive), Essex (R_1), 3RC-8 (R_2), Pentland Ace (R_3), DXD-3 (R_4), 3XE-1 (R_1R_2), 4739-58 (R_1R_3), 3WM-19 (R_1R_4), 1682c(1) (R_2R_3), TI-5 (R_2R_4), 1488b(1) (R_3R_4), and 3XX-1 ($R_1R_2R_4$). Since the different isolates of *P. infestans* studied varied in race characters, the differential hosts used varied with the isolate.

The inoculation techniques varied slightly with each experiment but in general sporangia from sporulating tuber slices or from test tubes were suspended in distilled water and either sprayed on entire plants or brushed on individual attached leaves. The inoculated plants were held at 18° C and 100 per cent relative humidity for 24 hours and then moved to a greenhouse maintained at 20° C. air temperature.

Experimental Results

Single-Sporangium Isolations

Isolate 43.—When obtained from Dr. J. S. Neiderhauser, The Rockefeller Foundation, Mexico, via Fort Detrick, Maryland, this isolate was tentatively labeled race 1,2. Differential hosts of the recessive, R_1, R_2 and R_1R_2 genotypes were heavily infected but in addition, a few lesions appeared on R_4, R_1R_4, R_2R_4 and $R_1R_2R_4$ plants. Thus, the isolate reacted as a mechanical mixture of races 1,2 and 1,2,4 with a small percentage of race 1,2,4 present in the mixture. Five single-sporangium cultures made from isolate 43 severely infected R_2 plants but, in addition, two formed single lesions on the $R_1R_2R_4$ host. An isolate obtained from the single lesion on the $R_1R_2R_4$ plant inoculated with one of the single-sporangium cultures, severely infected the latter host upon reinoculation.

Isolate F1.—This isolate was obtained from an infected tomato fruit sent from Homestead, Florida by Dr. R. A. Conover. When the potato differential hosts were inoculated, lesions appeared on the recessive, R_3 and R_4 plants but not on the R_3R_4 host. Isolations to agar were made from the R_3 and R_4 infected plants. The isolate from the R_4 plant produced many lesions on the R_3, R_4 and R_3R_4 plants whereas the isolate from the R_3 plant produced heavy infection on the R_3 plant with only a few lesions on the R_4 and R_3R_4 plants. When the above test was repeated, similar results

were obtained with the R_4 isolate but the R_3 isolate produced lesions only on the R_3 plants. Thus it appeared that the original isolate was a mixture of races 3 and 3,4. Of 12 single-sporangium cultures made from an agar isolate obtained from a lesion on the infected R_4 plant of the first experiment, 10 proved to be race 3,4 and 2 were identified as race 3.

Isolate CM 123.—Obtained from J. L. Howatt of Fredericton, N. B., Canada, as race 1,2,3, this isolate heavily infected R_1, R_2, and R_3 plants and in addition produced a few lesions on the R_4 host. Thirteen single-sporangium cultures were made from one of the small sporulating lesions appearing on the R_4 plant and used to inoculate other recessive and R_4 plants; equally heavy infections were produced on both hosts by all 13 isolates. Only one of the single-sporangium isolates was used to inoculate R_1, R_2 and R_3 hosts which became heavily infected. This indicated that race 1,2,3,4 had been obtained after one passage through the R_4 host.

Isolates G-C and G-K.—These isolates were received from Dr. K. M. Graham, Ottawa, Canada, as potato race 1. When tested on the potato differential hosts, the R_1 plants were severely diseased but in addition, a few spreading lesions appeared on R_4 and R_1R_4 plants. Four single-sporangium cultures made from isolate G-C all reacted as race 1,4 when used to inoculate individual attached leaves of R_1, R_4 and R_1R_4 plants; if race 1 was present it was masked by the presence of race 1,4. Of four single sporangium cultures made from isolate G-K, one infected attached leaves of only the recessive and R_1 plants, 2 infected recessive, R_1, R_4 and R_1R_4 plants, and 1 failed to infect any of the hosts; thus it appeared that race 1 and 1,4 existed in the culture as a simple mechanical mixture.

Single-Zoospore Isolations

Single-sporangium cultures of the above isolates indicated that they existed as mixtures of two races and that they could be sorted into their two component parts by single-sporangium isolations. Single sporangia are multinucleate and it was not known whether the mixtures in the original cultures existed as simple mechanical mixtures or if they contained mixed nuclei of different race characteristics in heterocaryotic mycelium. Since single zoospores usually contain a single haploid nucleus (6), a study was made of the race 4 character in several single-zoospore cultures.

Isolate WV-1z4 .—Isolate WV-1 was obtained in 1949 from an infected Katahdin tuber and identified as race 0. The mass isolate severely infected recessive plants but formed only necrotic flecks on R_1, R_2, and R_3 plants. A few spreading lesions often occurred on R_4 plants inoculated with this isolate. A single-zoospore culture (labeled WV-1z4) made from the mother culture also formed a few lesions on R_4 plants in addition to severely infecting the recessive Irish Cobbler plants. In contrast, sixteen single-sporangium and six single-zoospore cultures obtained from lesions produced by WV-1z4 on R_4 plants produced heavy infection on both the recessive and R_4 plants. Thus, a virulent race 4 was obtained from a single-zoospore isolate of race 0 by reisolation after one passage through an R_4 plant.

Isolate M7z1.—This single-zoospore culture of isolate M7 previously determined to be a potato race 0 produced many lesions on recessive plants and three spreading lesions on R_4 plants. The R_1, R_2, and R_3 plants developed only necrotic flecks following inoculation. A single-zoospore culture from one of the 3 lesions on the R_4 plant severely infected both the recessive and the R_4 plant. Thus, as occurred with the above isolate, a virulent race 4 was obtained from a single-zoospore culture of race 0 following one passage through an R_4 plant.

Isolate G-Cz1.—As noted above, all single-sporangium cultures from isolate G-C produced apparently equal infection on the recessive, R_1, R_4, and R_1R_4 plants; if race 1 was present it was masked by the presence of race 1,4. When the single-gene differential hosts were inoculated with a single-zoospore isolate from G-C(G-Cz1), the recessive and R_1 plants were severely infected whereas the R_4 plants had only five spreading lesions; the other genotypes showed only the necrotic fleck reaction. In contrast, a single-zoospore culture from one of the lesions on the R_4 plant severely infected the recessive, R_1 and R_4 plants indicating that a virulent race 1,4 developed from a single-zoospore isolate derived from a culture formerly considered to be race 1.

Isolate S-B^{1}z1.—When isolate S-B^1, obtained from Dr. W. Black (1) of Scotland, was used in race identification tests, it was noted that occasional lesions developed on R_4 plants considered to be resistant. Isolate S-B^{1}z1, a single-zoospore isolate from S-B^1, produced severe infection on recessive and R_1 plants but, in addition, produced one spreading lesion on the R_4 host. A single-zoospore culture from the lesion on the R_4 plant severely infected the recessive, R_1 and R_4 hosts; thus a virulent race 1,4 was again derived from a single-zoospore culture of race 1 following one passage through an R_4 plant.

Isolate 63z1.—Obtained from Puerto Rico via Fort Detrick, Maryland, isolate 63 was identified as potato race 3 upon arrival. When the single-gene differential hosts were inoculated with 63z1, a monozoosporic isolate from it, many spreading lesions appeared on the recessive and R_3 plants and, in addition, 3 small lesions which continued to spread, appeared on the R_4 host. Inoculations with a single-zoospore culture from a lesion on the R_4 plant severely infected the recessive, R_3 and R_4 plants and thus was identified as a virulent race 3,4.

Discussion

The above results lead to the conclusion that the race 4 character may appear in almost any isolate of *P. infestans* without regard to the race 1, 2, and/or 3 character which which may be present. In the 10 isolates studied, race 4 appeared as an addition to the other race characters previously recognized. For instance, race 4 appeared in isolates of race 0 as race 4, in isolates of race 1 as race 1,4, in isolates of race 3 as 3,4, in an isolate of race 1,2 as 1,2,4, and in an isolate of race 1,2,3 as race 1,2,3,4. Inoculations with a culture previously considered as not having the race 4 character left the impression that the culture was a mixture of two races with the race containing the 4 character present in a small proportion.

As an example, when present in a culture of race 0 the recessive plants were severely infected whereas the supposedly resistant R_4 plants would have usually 1-5 lesions. In contrast, isolates from these lesions on the R_4 plants severely infected both the recessive and R_4 plants.

In one of the first cultures studied (isolate G-K), it appeared that race 1,4 was present as a simple mechanical mixture with race 1 since single-sporangium cultures appeared to react as two distinct races. However, in another culture (isolate 43), the race 4 character appeared to be present as a mixture in single-sporangium cultures. This suggested that the race 4 character was present as a mixture in heterocaryotic mycelium.

When single-zoospore cultures, theoretically derived from a single haploid nucleus, were made in an effort to completely remove the race 4 component from the mixture, they too reacted as the mother culture and as certain single-sporangium cultures in that a few lesions appeared on supposedly resistant R_4 plants. Thus, it appears that race 4 arises by mutation with the mutant nucleus carried along in heterocaryotic mycelium.

It is probable that the change by a single-zoospore isolate to include the race 4 characteristic occurs during the process of growth either in the plant or on agar. The mutant nucleus, increasing in number by nuclear division along with the original nuclei, would eventually appear in zoospores and produce lesions on R_4 plants. When conditions are optimum for infection and a concentrated inoculum is used, the chance of picking out the mutation would be greater than if inoculations were carried out under the opposite conditions. Although no effort has been made to study the effect of inoculum concentration on the appearance of the race 4 character, it has been observed during routine inoculations that when relatively poor infection occurred on the recessive hosts, the R_4 resistant plants usually remained free from spreading lesions. The above may explain why a few of the single-sporangium isolates made in the early phase of this study failed to produce the usual few lesions on R_4 plants.

Though the results reported herein strongly point to mutation of nuclei within the thallus as the reason for the appearance of race 4 in all cultures thus far studied, it is still possible that this character was carried along as a mixture in single zoospores. Hiddema and Kole (4) as well as the authors, have observed fusion of zoospores in pairs. Nuclear stains (unpublished data of the authors) reveal that as high as 25 per cent of the zoospores in some cultures may be binucleate. However, if the zoospores isolated in these studies were binucleate and the race 4 character was present in one of the nuclei, it seems logical to assume that the R_4 plants inoculated with this culture would show many lesions. Such did not occur in these studies since no more than 5 lesions appeared on R_4 plants with any single-zoospore culture, whereas recessive plants were severely infected by the same inoculum.

If mutation toward the race 4 character is going on continuously in all cultures of *P. infestans*, the question arises as to why a culture does not eventually chage to a pure race 4. Since this has never been observed, except when screened out by passage through R_4 plants, it is postulated that back mutation to the original race goes on at the same rate. Experiments with differential hosts designed to screen out the lower order race

arising by back mutation have not been successfully carried out since hosts susceptible to this race are also susceptible to the specialized race infectious to R_4 plants. Back mutation might be used to explain the lack of infection on R_4 plants by two single-sporangium cultures obtained from lesions on R_4 plants produced by isolate F1. However, in this case it is also possible that the original nucleus was carried along through sporangial penetration and showed up in a pure state in two of the sporangia picked from the lesions.

The theory that cultures rapidly mutate to include the race 4 character is offered as an explanation for high percentages of race 4 found during race surveys carried out in different countries. If concentrated inoculum from vigorously growing cultures were used under conditions optimum for infection, it would be surprising if the race 4 character was not detected in a high percentage of isolates tested. The use of the detached leaf method of race identification would be even more favorable for the detection of race 4 since there would be little run-off of inoculum. However, future work may reveal that some isolates do not readily mutate to include race 4. Takase (9) has suggested that the reason race 4 is now found more frequently than race 0 is that plants with the R_4 gene have a weaker type of resistance than that of plants with the other dominant genes. He noted that tubers of R_1, R_2 and R_3 genotypes showed varying types of general necrosis when inoculated with a concentrated zoospore suspension of race 0, whereas tubers of the R_4 genotypes showed a type "f" reaction described as an initial appearance of brown fibrous tissues followed by the later emergence of a considerable quantity of aerial hyphae. Based on the work reported herein, this type "f" reaction would be considered as being due to the presence of race 4 in the inoculum giving a susceptible type reaction along with a resistance reaction. As the mutant race 4 spread through the tuber, the quantity of aerial mycelium would increase.

Summary

Studies involving single-sporangium and single-zoospore isolates of 10 cultures of different potato physiologic races of *P. infestans* suggest that any race will readily change to include the race 4 characteristic in addition to those previously recognized. The character appeared in isolates of race 0 as race 4, in isolates of race 1 as race 1,4, in isolates of race 3 as race 3,4, in an isolate of race 1,2 as race 1,2,4 and in an isolate of race 1,2,3 as race 1,2,3,4. This change was interpreted as being due to mutation of nuclei within the thalli with the mutant nuclei being carried in heterocaryotic mycelium along with the original nuclei. The ability of the fungus to mutate readily to include the race 4 characteristic is offered as an explanation for the high percentages of race 4 noted in race surveys made by different workers in various countries.

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ELECTRONIC HEATING AS A MEANS OF STERILIZING POTATO BAGS CONTAMINATED WITH BACTERIAL RING ROT[1]

D. S. MacLachlan[2]

Introduction

Growers of seed potatoes in certain areas of Canada use second-hand bags to transport cut seed to the fields, and to transport the harvested crop to storage. In many cases, outbreaks of bacterial ring rot on seed potato farms have been traced to infection from contaminated bags.

Two methods have been used commercially in Canada to treat used potato bags. Heating in a vault until the temperature at the center of the bale of bags reaches 120° F., and holding this temperature for a period of one hour is the most common treatment. MacLachlan *et al.* (3) in 1953 proposed fumigation with ethylene oxide as a means of eliminating ring-rot bacteria from bags. Infra red heating has been shown to be effective (2), but this type of heating has not been used commercially because it causes rapid deterioration of the jute fibers. Small lots of bags may be soaked in disinfectant and dried (2), but this is a slow process.

In recent investigations, Richardson (4) found that a temperature of 150° C. for 10 minutes was necessary to kill ring-rot bacteria on jute strands. He also obtained evidence that the ring-rot bacteria, either by selection or mutation, could become resistant to temperatures which normally killed the organisms. These results indicated that the dry heat treatment currently in use might not be effective in killing ring-rot bacteria on bags. Richardson's results cannot, however, be applied directly to the conditions existing in baled bags, as the bales hold the heat for some considerable time. To date there is no evidence that a temperature of 120° F. for several hours will not destroy the ring rot organism.

The present experiments with electronic heating were started because of the high degree of penetration of electrons through nonconducting materials, and because of the differential in heating to be expected within the bacteria as compared to that within the jute strands of the bag. An electronic oven has been in use at the Eastern States Farmers' Exchange, Buffalo, N. Y., for some years. This oven is used to sterilize feed bags in 250-bag bales. A 60-minute treatment is claimed to make the bags completely free of disease-producing organisms (1).

Materials and Methods

A Gurney-Tappan electronic range supplied through the courtesy of Gurney Products Ltd., 380 Ste. Croix Blvd., St. Laurent, Quebec, was used as the source of electronic heat. The oven was equipped with a 2.450 megacycle oscillator. The Hi-Speed setting consumed 3100 watts.

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Contribution No. 1696, from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario.
[2] Plant Pathologist.

The test material was composed of 3-inch strands of jute, soaked for 3 hours in a heavy suspension of ring rot bacteria, and dried for 48 hours in a dessicator over calcium chloride. The strands were placed in sterile test tubes, 5 strands to a tube, and inserted at various positions in a bale of bags. After treatment, the test tubes were removed, and 15 ml. of Richardson's medium (4) was poured aseptically over the strands. The material was then incubated for 10 days at 21° C. on a shaker. Gram-stained smears were prepared from the medium in each tube, and the efficiency of the treatment was determined on the basis of the presence or absence of ring rot bacteria.

Fifty bags, folded double, and tied tightly with heavy cord, were placed in the oven. The thickness of the treated bales was thus the equivalent of 100 bags. Three test tubes containing the test material were placed in the bale between the first and second bag from both the top and bottom, and at 10-bag intervals throughout the bale. Immediately following the treatment, thermometers were inserted into the bale at the same locations as the test material. Temperature readings were taken at one-hour intervals for three hours.

Results of Treatments

Treatments of 10, 15, 20 and 30 minutes were used and each treatment was replicated five times. The Hi-Speed setting on the oven was used in all treatments. The results of the treatments are recorded in tables 1 and 2.

In each trial, the temperature was highest at or near the center of the bale and decreased toward the outside. The temperature at the center of the bale remained quite high even 3 hours after treatment. An exposure of 30 minutes was required to kill all the bacteria in the test materials. This was accomplished by raising the temperature of the bags on the outside of the bale to 230° F. In the three hours following treatment, this temperature dropped to 169° F.

If a method could be found which would produce more even heating, particularly towards the outside of the bale, the exposure time might be lessened. In an attempt to produce this effect, the three layers of bags on the outside of the bale were soaked in water before treatment. In a 20-minute exposure in the oven, the bacteria were killed in the top-outside layer of bags, but were still alive in the remaining portions of the bale. The temperature in the dampened bags was 242° F., while at the center of the bale it was 160° F.

Conclusions

A 30-minute exposure in a 2.45 megacycle, 3100-watt electronic oven was sufficient to kill all the ring rot bacteria in heavily contaminated jute strands placed throughout a bale of 100 bags. The maximum temperature reached within the bale was slightly over 270° F., at the center, but the bacteria were killed at a temperature of 230° F. at the outside. It has been shown experimentally that temperatures of over 300° F. and an exposure of 10 minutes are necessary to kill the organism (4). In the present trials, a temperature of 230° F. dropping to 169° F. over a 3-hour period killed all the ring rot bacteria. This inconsistency may be explained

TABLE 1.—*Survival of ring rot bacteria in baled bags after exposure to electronic heating.*

Duration of Treatment	Position of Test Material (Bag Thicknesses from Top)	Bacterial Ring Rot Readings					Bale Temp.* After Treatment			
		Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	0 Hr.	1 Hr.	2 Hrs.	3 Hrs.
10 Min.	1	+	+	—	+	+	131	93	82	80
	10	+	—	+	+	+	134	93	85	82
	20	+	+	+	+	+	139	96	93	90
	30	—	—	—	+	+	146	109	101	98
	40	—	—	—	—	—	176	142	134	128
	50	—	—	—	—	—	192	164	152	136
	60	—	—	—	—	—	187	161	149	138
	70	—	—	—	—	—	182	160	148	136
	80	—	+	—	—	—	175	158	141	130
	90	—	—	—	+	—	161	153	132	118
	99	—	—	—	+	+	153	144	126	112
15 Min.	1	+	+	+	+	+	178	111	91	83
	10	—	—	+	—	—	198	126	110	88
	20	—	—	—	—	—	206	152	116	94
	30	—	—	—	—	—	211	154	118	97
	40	—	—	—	—	—	212	159	121	100
	50	—	—	—	—	—	218	166	133	109
	60	—	—	—	—	—	215	162	133	110
	70	—	—	—	—	—	209	159	129	105
	80	—	—	—	—	—	203	152	123	101
	90	—	—	—	—	—	191	147	120	96
	99	—	+	—	+	+	181	139	117	91
Controls		+	+	+	+	+				

*Degrees Fahrenheit, average of 5 replicates.

by the prolonged exposure to a lower temperature, or by the type of heating. High protein materials, such as bacteria, become heated more rapidly in electronic heating than do poor conductors such as jute strands. The temperature within the bale of bags would not, under the conditions of this experiment, truly represent the temperature to which the bacteria themselves were exposed. Although the relative humidity within the baled bags was not determined, water droplets collected on the sides of the oven during the treatment. The humidity during the treatments, may have, to some extent, influenced the rate at which the ring rot organism was killed. A recent publication by Richardson (5) indicates that high relative humidity has a marked effect on the susceptibility of the ring rot organism to heat treatment.

TABLE 2.—*Survival of ring rot bacteria in baled bags after exposure to electronic heating.*

Duration of Treatment	Position of Test Material (Bag Thicknesses from Top)	Bacterial Ring Rot Readings					Bale Temp.* After Treatment			
		Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	0 Hr.	1 Hr.	2 Hrs.	3 Hrs.
							204	178	156	131
20 Min.	1	—	+	+	—	—	219	199	164	140
	10	—	—	—	—	—	221	202	176	149
	20	—	—	—	—	—	242	221	191	162
	30	—	—	—	—	—	251	226	198	173
	40	—	—	—	—	—	253	228	214	196
	50	—	—	—	—	—	255	227	210	189
	60	—	—	—	—	—	247	224	201	179
	70	—	—	—	—	—	238	218	198	171
	80	—	—	—	—	—	225	211	193	162
	90	—	—	—	—	—	218	202	185	147
	99	—	—	—	+	—				
30 Min.		No Viable Bacteria								
	1						230	196	185	169
	10						245	210	198	183
	20						258	233	221	197
	30						260	240	226	200
	40						268	241	227	201
	50						271	241	227	200
	60						269	240	227	200
	70						267	238	227	199
	80						259	231	221	195
	90						248	228	216	197
	99						233	220	206	189
Controls		+	+	+	+	+				

*Degrees Fahrenheit, average of 5 replicates.

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SOME PLANT NUTRIENT RELATIONSHIPS IN THE POTATO CROP GROWN ON A CALCAREOUS SOIL[1]

JAY L. HADDOCK AND RAY D. JACKSON[2]

A number of investigators (1)[3] (4) (6) (7) (8) have presented data on the chemical composition of the potato crop, but few attempts have been made to characterize poorly-nourished and well-nourished plants (2) (9) (11) (13) (15). The "Foliar Diagnosis" method of Thomas (12-16) is a promising procedure to evaluate the chemical composition of crop plants.

The seasonal growth rates of tops, tubers, and roots of Russet Burbank potatoes grown on a well-drained, calcareous loam soil under irrigation in northern Utah have been reported (4). Data were also presented showing the accumulative total and average daily increments of nitrogen, phosphorus, and potassium absorbed by the potato crop.

Data were available for 13 weekly sampling dates from tuber formation to harvest. In order to have some basis for comparison, leaf samples similar to those used by Thomas (12) were taken at 74 and 124 days after planting to study his quantitative and qualitative factors.

The Millville loam soil on which this experiment was conducted (4) is a deep, well-drained uniform textured soil with approximately 50 per cent calcium carbonate equivalent and a pH near 8.00. Exchangeable potassium is approximately 300 pounds per acre. Commercial fertilizer was applied at the rate of 80 pounds of nitrogen and 44 pounds of phosphorus per acre. A yield of 510 bushels of marketable potatoes was obtained.

The two specific objectives in this study were:

1. To obtain a better understanding of the seasonal nutritional changes which occur in various parts of the potato crop under irrigation in a calcareous soil.

2. To compare the seasonal nutritional changes which occur in leaf tissue with those which occur in tops, roots, and tubers of the potato crop.

RESULTS AND DISCUSSION

Thomas *et al.* (16) plot their "quality factor" data on trilinear coordinate graphs and their "quantity factors" are presented in tables. However, the data can be illustrated better by the simple linear graphs, used in this article.

QUANTITY FACTOR

The data in figure 1 show seasonal changes in the "quantity factor" which is the sum of percentages of $N + P_2O_5 + K_2O$ in each particular tissue. These data show a significant linear seasonal decline for tops, roots, and tubers. It is evident that for all potato plant tissues, the "quantity

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[2]Soil Scientists, at Logan, Utah and Fort Collins, Colorado, respectively.
[3]Numbers in parentheses refer to literature cited.

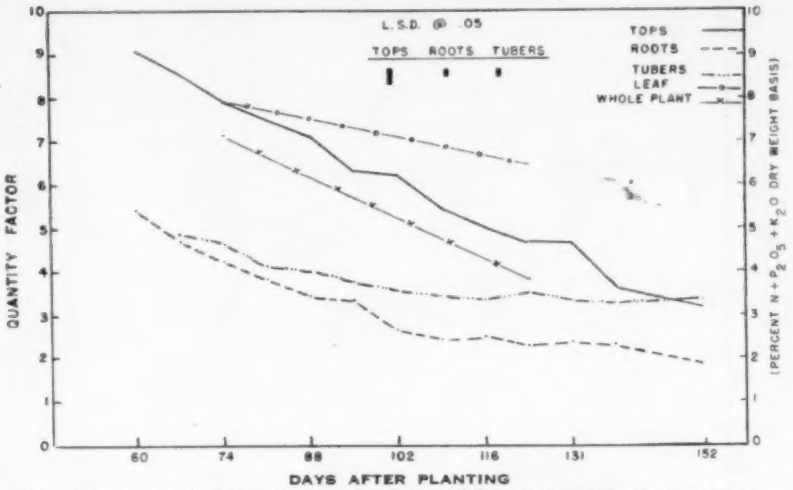

FIGURE 1.—Seasonal changes in quantity factor of Russet Burbank potato tops, roots and tubers (1954).

factor" decreases with age. A similar trend has been shown by Thomas (12) for the potato leaves of the same physiological age. Data are shown in figure 1 for potato leaves of similar physiological age to those selected by Thomas. The rate of seasonal decline, however, is less rapid in leaves than it is in the tops,roots, or whole plant. The "quantity factor" for the whole plant parallels that for the tops. Naturally, the tops, which constitute more than 85 per cent of the total dry matter at 60 days, dominate the chemical make-up of the plant. However, at the end of 152 days the tubers constitute nearly 80 per cent of the total dry matter and dominate the chemical make-up of the entire plant. The "quantity factor" for leaves, early in the season, appear to be similar to the tops and hence to the entire plant. However, as the plant matures the "quantity factor" for leaves represents the "quantity factor" for tops, roots, tubers, or whole plant less accurately.

QUALITY FACTOR

Before examining the "quality factor" keep clearly in mind the dominating influence of the tops and tubers on the chemical composition of the entire plant at various stages of growth. The "quality factor" for nitrogen is shown in figure 2. These data show a significant linear seasonal increase for tops, roots, and tubers. Although the absolute nitrogen percentage does not increase with season, it does increase seasonally relative to the total nutrient ($N + P_2O_5 + K_2O$ as milligram equivalents) composition. Potato leaves and whole plant show a decline in the nitrogen "quality factor" seasonally. This is a good example of how chemical ratios may be misleading. The explanation for the whole plant giving this false impression, lies in the fact that the tops dominate the chemical ratios early in the season while the tubers control late season ratios.

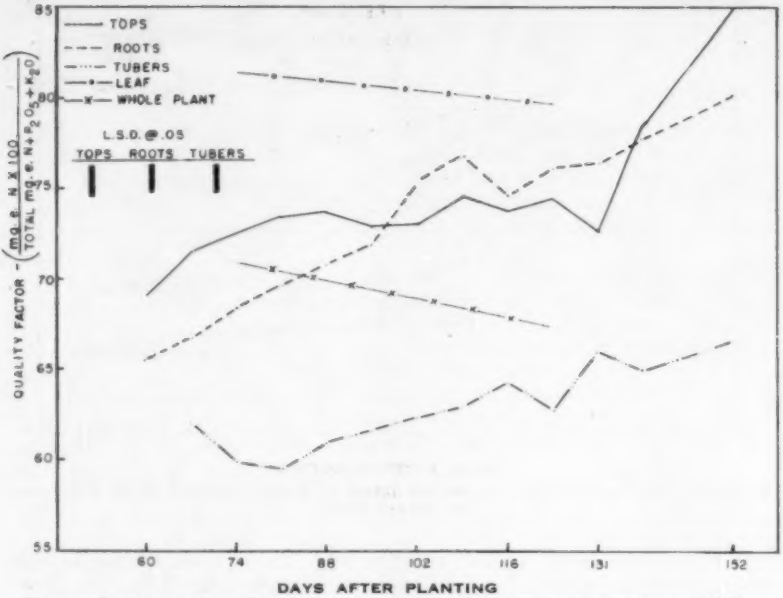

FIGURE 2.—Seasonal variation in nitrogen quality factor of potatoes (1954).

Thomas (12) presents data showing a seasonal decrease in the nitrogen "quality factor" on all plots where yields were satisfactory and a seasonal increase where yields were relatively low. However, data which he gives suggest that his nitrogen "quality factor" for leaves of high yielding plots should show values near 65 per cent which is considerably lower than those shown for potato leaves in figure 2.

The data presented in figure 3 show a significant linear seasonal decline for roots and tubers relative to phosphorus "quality factor." However, the tops show a significant quadratic seasonal relation with the low point 95 days after planting. The leaf data show no seasonal change. The whole plant data show a seasonal increase in phosphorus quality factor. There is a seasonal decrease for tops, roots, and tubers. The leaf does not appear to reflect a seasonal change in phosphorus quality factor similar to other plant tissue. The explanation for the contrary behavior of the whole plant is again related to influence of tops and tubers dominating the chemical make-up at different seasons. Data which Thomas (12) provides indicate that the phosphorus quality factor for leaves should be about 5.5 per cent or a little above that shown in figure 3.

Data plotted in figure 4 show a highly significant linear decline between potassium "quality factor" and days after planting for tops, roots, and tubers and an increase for leaves and whole plant. The leaf data agree with Thomas' (12)data on high-yielding plots but the values shown here for potassium "quality factor" are about half the magnitude of values given

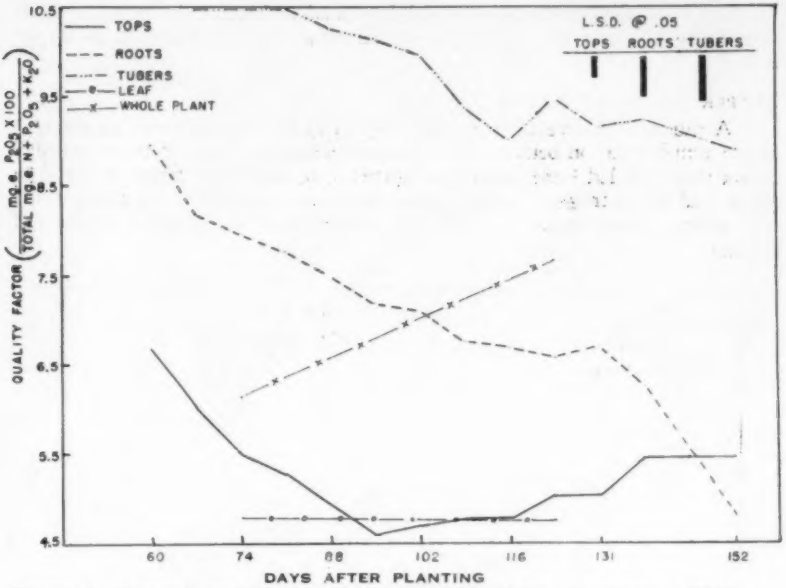

FIGURE 3.—Seasonal variation in phosphorus quality factor of potatoes (1954).

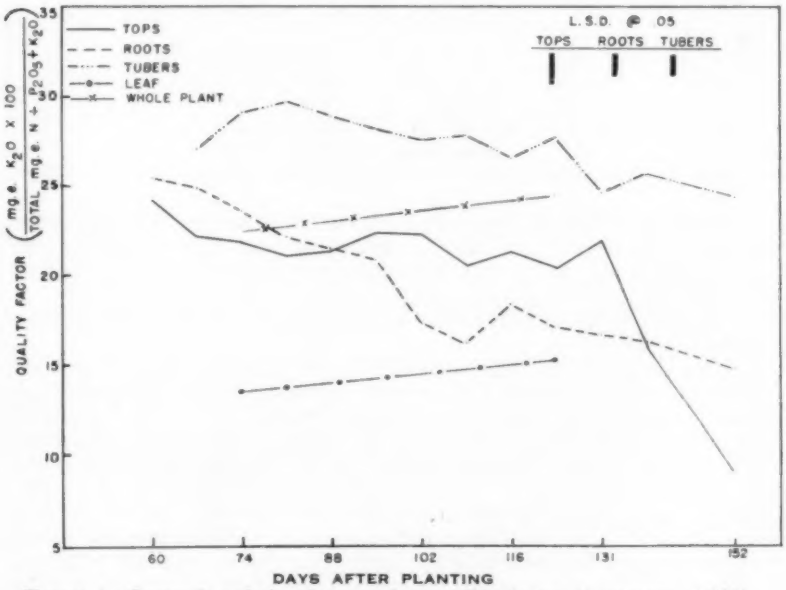

FIGURE 4.—Seasonal variation in potassium quality factor of potatoes (1954).

by him. Leaf data in figure 4 show a potassium quality factor of 15 percent while Thomas' data show a seasonal range varying from 25 to 30 per cent.

Simple Nutrient Ratios

A number of investigators (3) (5) (10) have manifested an interest in the simple relation between two nutrient elements. Some of these seasonal ratios found in 1954 are shown in figures 5, 6, and 7. In figure 5 the data show that the nitrogen : potash ratio increases seasonally, for tops, roots, and tubers. Here again the leaf and whole plant tissue show a seasonal decline.

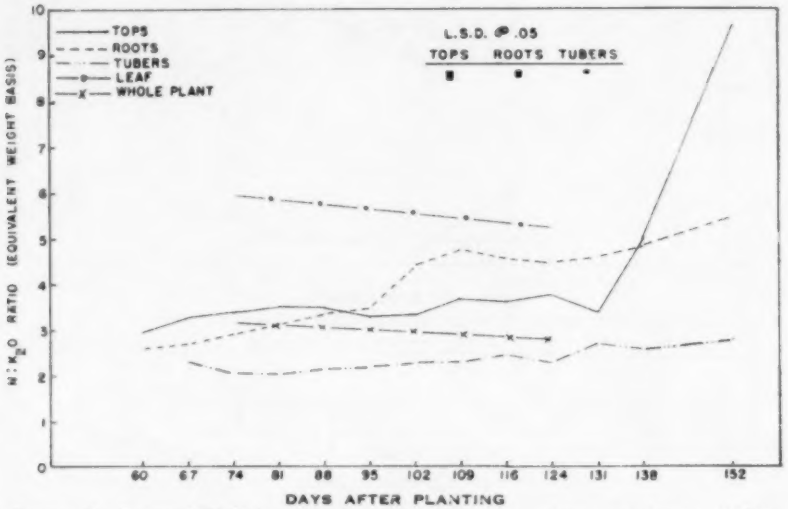

Figure 5.—Seasonal N:K_2O ratio of potato tops, roots, tubers, and leaves (1954).

The data in figure 6 shows a significant linear seasonal increase in the nitrogen : phosphoric acid ratio in tops, roots ,and tubers. However, the leaves show no seasonal change, while the whole-plant data show a seasonal decrease.

The data in figure 7 give little seasonal variation in the potash : phosphoric acid ratio.

Thomas and Mack (15) indicate that the potash content of the leaf should vary between 4.5 to 6.5 per cent. The value in this study although of similar physiological age, varied from 2.4 to 2.7 per cent K_2O. This suggests the possibility of potassium deficiency in the potato crop under consideration. Thomas' data also show that the "quantity factor" for leaves may vary between 8 and 12 per cent. Data on leaf composition for the two sampling dates shown in this study show the "quantity factor" to vary from 6.5 to 8.0 per cent. Since potassium is a dominant element in the "quantity factor" attention is again directed toward the possible deficiency of this element in the crop under consideration. Thomas and Mack (15)

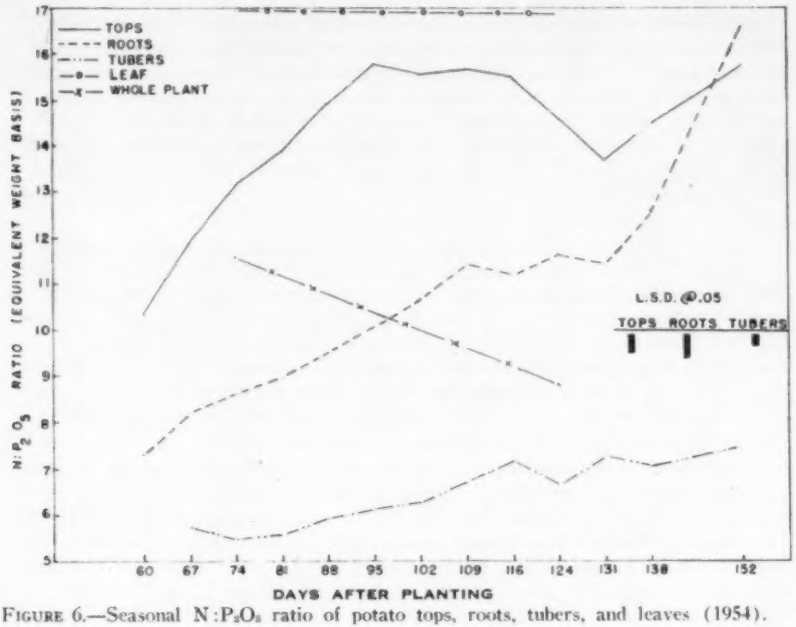

FIGURE 6.—Seasonal $N:P_2O_5$ ratio of potato tops, roots, tubers, and leaves (1954).

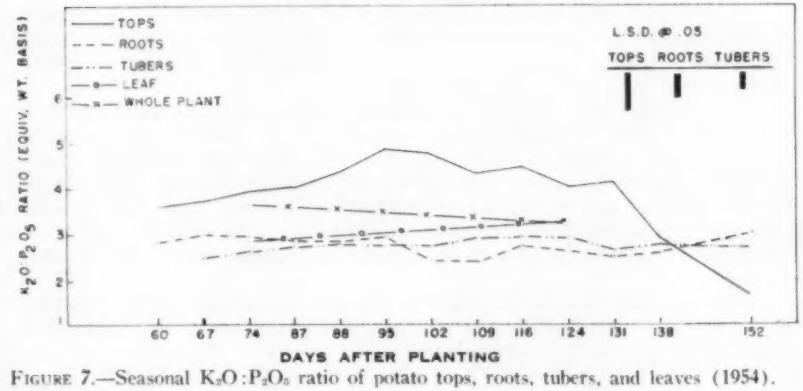

FIGURE 7.—Seasonal $K_2O:P_2O_5$ ratio of potato tops, roots, tubers, and leaves (1954).

present data for potato leaves which show that when the "quantity factor" for potassium is inadequate and the "quality factor" for nitrogen is adequate, nitrogen shows an increase and potassium a decrease in the latter part of the season. This is precisely what is shown in figures 2 and 4 by the tops, roots, and tubers. However, the leaves show the opposite relation. If Thomas' reasoning and observations are applied to the data given in figures 2 to 7 for tops, roots, and tubers, it is necessary to conclude that nitrogen was present in excess, phosphorus was adequate, and potassium was deficient.

Using Thomas' (12) data for potato leaves it would appear justifiable to concludé that the seasonal range in "quality factor" for nitrogen might vary between 60 and 70 per cent, for phosphorus between 4 and 6 per cent, and for potassium between 20 and 30 per cent. On this basis leaf data for the two dates shown in figures 2, 3, and 4 indicate that nitrogen is much above this range, phosphorus is adequate, and potassium is limiting. However, the slope of the lines between the two dates showing "quality factors" for leaves and whole plant would suggest a deficiency in nitrogen and an excess of potassium with phosphorus in adequate supply.

Admittedly, the data for leaf analysis presented herein is too limited to make conclusive statements relative to the validity of leaf analysis as a satisfactory basis for appraising the nutritional status of the potato plant.

On the basis of conclusions reached by Thomas and co-workers *viz.* that potash is the dominant factor leading to increased intensity of nutrition, coupled with the low intensity of nutrition shown by the leaf data in figure 1, there seems to be some indication that potassium is limiting on this soil for potato production. The seasonal trend of potassium "quality factor" of leaves in figure 4 does not support this view but the seasonal trend for potassium "quality factor" for tops, roots, and tubers agrees with this conclusion.

Is the leaf tissue, in fact, a better indicator of nutritional status than tops, roots, and tubers? If so, we have some contradictory conclusions to reconcile.

Summary

A study of the chemical composition of various parts of the Russet Burbank potato grown on a well-drained Millville loam soil shows some interesting seasonal relations. A yield of 510 bushels per acre suggests that the crop was fairly well nourished.

The potato crop showed a seasonal decline in Thomas' "quantity factor" for all tissues studied which agreed with his data for leaf analysis. However, the "quantity factor" is considerably below apparently desirable levels for the entire season. This combined with the seasonal behavior of quality factors" for nitrogen and potassium in tops, roots, and tubers, suggests the possibility of potassium deficiency. This conclusion is not indicated by leaf composition with respect to seasonal potassium "quality factor".

The seasonal "quality factors" for nitrogen, phosphorus, and potassium show consistent disagreement when tops, roots, and tubers are contrasted with leaf tissue from the same plant.

The simple ratios $N : K_2O$; $N : P_2O_5$ and $K_2O : P_2O_5$ for tops, roots,

and tubers indicate that nitrogen was in ample supply to this particular crop, and that potassium may have been somewhat limiting. This conclusion is not justified by these ratios in leaf tissue.

This study emphasizes the need for a re-examination of the theory (12-16) that "there is no fundamental physiological experimental basis to support the use of tissue other than the whole active leaf when one is trying to diagnose the mineral requirement of plants."

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SUBERIN AND WOUND PERIDERM FORMATION AND DECAY OF POTATO SLICES AS AFFECTED BY DURATION OF TUBER STORAGE AT 40° F.[1]

W. L. Smith, Jr. and Helen F. Smart[2]

Introduction

Since the work in Germany (1, 3, 4) near the beginning of this century interest in the ability of Irish potatoes to form suberin and wound periderm on injured surfaces has waxed and waned. The effects of oxygen, light, temperature and humidity on the formation of these barriers and the more rapid formation of barriers by immature or small potatoes than by fully mature or large ones have been shown (2, 3, 4). The influence of these barriers in preventing decay of tubers or inoculated tuber slices has been established (1, 5, 6), but little attention has been paid to the effect of duration of tuber storage on barrier formation and decay development. The purpose of the present investigation was (a) to study the formation of suberin and periderm on slices from tubers shortly after harvest and from tubers removed from 40° F. storage after various intervals and (b) to determine the relation between the duration of tuber storage and the development of bacterial decay of inoculated slices.

Materials and Methods

U. S. No. 1 tubers (size A) of the varieties Chippewa, Green Mountain, Irish Cobbler, Katahdin, Kennebec, Mohawk, Sebago, and Teton were obtained from Maine through the courtesy of F. J. Stevenson, formerly of the U. S. Department of Agriculture, Beltsville, Md. All varieties were harvested on September 25 and were stored at 40° F. and approximately 90 per cent relative humidity until used in the test.

Healing of slices from tubers of each variety was determined at four periods during the 8 months the tubers were stored. At each period of examination the tubers were washed and dried, and single slices approximately 10 mm thick were cut with an ethanol-flamed knife from each of 4 tubers of each variety. These slices were held in moist chambers at 70° F. After 1, 2, 3, or 4 days they were removed from the moist chambers and blocks of tissue cut from the parenchyma region of slices of each variety. Sections 20μ thick were cut from these blocks, placed in distilled water, stained and rated for the presence of suberin and wound periderm as previously described (5). A rating of 5 indicated the most extensive development of suberin and wound periderm and that of 0 no development.

The relation between barrier formation and decay was determined with the varieties Irish Cobbler, Katahdin, Kennebec, Mohawk, Sebago and Teton at 3 periods during the 8 months the tubers were stored. When the tubers were removed from the 40° F. storage, 24 slices of each variety

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were cut and held in moist chambers at 70°. Six slices of each variety were removed after 1, 2, 3 or 4 days. Two slices of each variety were examined for barrier formation at each daily period in the manner described. The other 4 slices of each variety at each daily period were inoculated with a 1:1000 water dilution of a 48 hour broth culture of *Erwinia atroseptica* (v. Hall) Jennison and returned to a moist chamber. They were given numerical ratings for decay after 2 additional days at 70° (5). A rating of 4 indicated complete decay and that of 0 no decay.

Results

Differences within or between varieties in suberin formation were most apparent after 1 day at 70° F. (Figure 1). All varieties except Green Mountain developed more suberin in October (shortly after harvest) than in January (3½ months after harvest). The decrease in ratings between the two examination periods was more pronounced for Irish Cobbler, Kennebec and Katahdin than the other varieties. Storage of tubers until March (5½ months) or May (8 months) caused little or no further change on suberization of slices. After 2 days at 70°, differences due to duration of storage or variety, were not so pronounced.

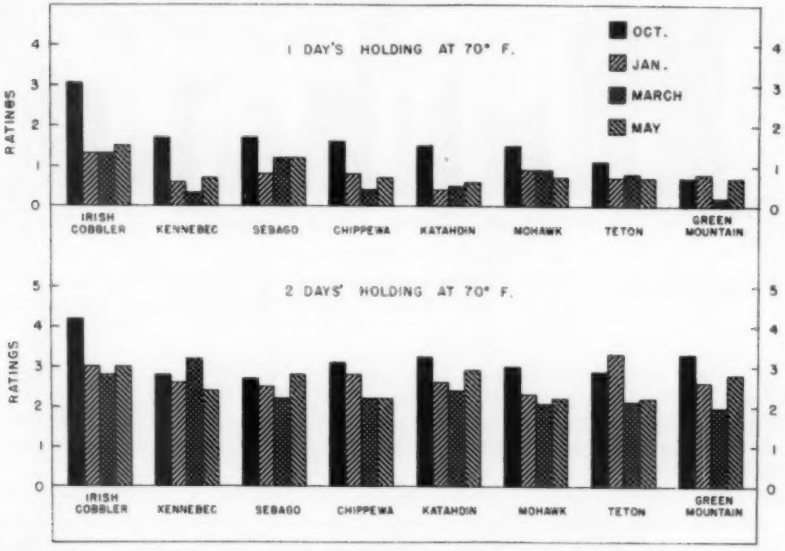

FIGURE 1.—Ratings of suberin formation of eight varieties of Irish potatoes as related to duration of tuber storage at 40° F.

Storing potatoes from October to January had an effect on wound periderm formation similar to that on suberin formation. Differences in wound periderm ratings of the varieties were most apparent on slices held 3 days at 70° F. (Figure 2). Slices from Kennebec, Chippewa, Katahdin,

Mohawk and Teton formed considerably less wound periderm after 3 days at 70° in January than October. The decrease in this barrier was not so pronounced on slices from Irish Cobbler or Sebago, while Green Mountain slices had approximately the same rating at both examinations. Storage of tubers for longer periods caused little or no further change in wound periderm formation. Differences between varieties also in many instances were apparent on slices held 4 days at 70°.

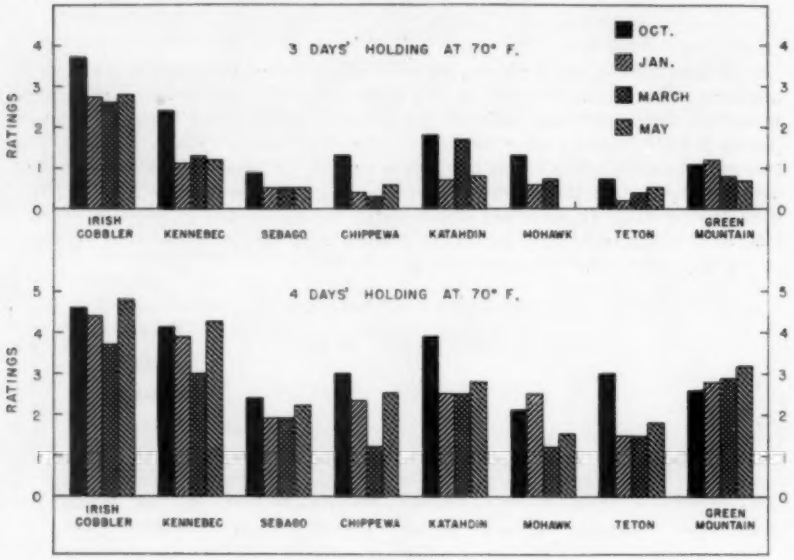

FIGURE 2.—Ratings of wound periderm formation of eight varieties of Irish potato slices as related to duration of tuber storage at 40° F.

Slices from Irish Cobbler tubers usually had higher average ratings at each examination for both suberin and periderm than any of the other varieties. The other varieties did not consistently differ in suberin formation at the different period of examination but Kennebec usually formed more wound periderm.

The relation of duration of storage to average formation of suberin is shown in table 1. Suberin was formed after 1 day at 70° F. regardless of the length of tuber storage and continued to be formed throughout the 4-day examination period with a somewhat decreased rate after the second day. The average suberin ratings were consistently higher in October than in January. Very little change in the rate of suberin formation occurred throughout the remainder of the storage period. Within 3 days wound periderm formed on slices at each of the examining periods (Table 2). The average ratings were consistently higher on slices examined in October than on those examined in January. There was little or no difference in

TABLE 1.—*Average formation of suberin on potato slices held at 70° F. as influenced by the duration of tuber storage at 40°.*

Days Slices Held at 70° F.	Average Slice Rating[1] in —				L.S.D.	
	October[2]	January	March	May	5 Per cent	1 Per cent
1	1.61	0.78	0.66	0.85	.42	.56
2	3.13	2.68	2.37	2.56	.38	.51
3	4.39	3.76	3.59	4.06	.27	.36
4	4.86	4.40	4.88	4.67	.36	.48
L.S.D.: Per cent						
5	0.63	0.33	0.32	0.30		
1	.84	.44	.43	.41		

[1]Average of 4 slices each of 8 varieties. An average rating of 0 equals no barrier and that of 5 most extensive barrier development.
[2]Approximately 3 weeks after harvest.

TABLE 2.—*Average formation of wound periderm on potato slices held at 70° F. as influenced by the duration of tuber storage at 40°.*

Days Slices Held at 70° F.	Average Slice Rating[1] in —				L.S.D.	
	October[2]	January	March	May	5 Per cent	1 Per cent
3	1.63	0.89	0.94	0.89	.31	.42
4	3.20	2.71	2.17	2.84	.43	.58
L.S.D.: Per cent						
5	0.29	0.31	0.30	0.25		
1	.40	.43	.42	.35		

[1]Average of 4 slices each of 8 varieties. An average rating of 0 equals no barrier and that of 5 most extensive barrier development.
[2]Approximately 3 weeks after harvest.

the rate of formation of this barrier on the slices during the remaining months of storage.

The development of decay is shown to be closely related to the formation of the barriers, which in turn is related to the duration of storage of the tubers and the number of days the slices are held at 70° F. before inoculation (Figure 3). Suberin, periderm, and decay ratings are given as averages for six of the varieties previously mentioned. At each examination period the average decay ratings on slices held 1 day at 70° before inoculation were always higher than on slices held at 70° for 2, 3 or 4 days before inoculation. In November the decay ratings were considerably less on slices held 2, 3 or 4 days before inoculation than on slices held only 1 day. When tubers were stored at 40° until February or April decay ratings were not appreciably lower until slices were held at 70° for 3 or 4 days before inoculation. At each examination period the least decay developed when the slices had the highest average ratings for suberin and periderm.

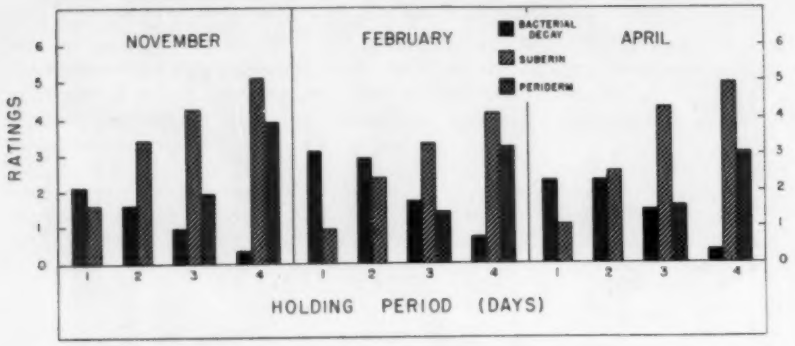

FIGURE 3.—Average suberin, wound periderm and decay ratings of 6 varieties of potato slices as influenced by duration of tuber storage at 40° F. and holding period at 70° before inoculation.

These data show that slices with the greatest barrier formation and slices from tubers with the shortest storage period at 40° developed the least decay.

DISCUSSION

The data presented show that protective barriers form more rapidly and extensively on slices cut from potatoes shortly after harvest than on slices from similar tubers stored at 40° F. for several months. They further show that bacterial decay is inversely related to rapidity of barrier formation. Under commercial handling operations potatoes usually are subjected to temperatures at which suberization and wound periderm formation will occur before they reach the final storage temperatures of 38° to 40°. These data show that even at 70° approximately 4 days are necessary for the two barriers to form sufficiently to effectively reduce bacterial decay on freshly harvested potatoes. They further show that tubers do not lose the ability to form these barriers even though they are stored several months at 40°. However, after a few months of storage the rapidity of barrier formation is considerably reduced. If fresh injuries are produced during handling after storage a longer period at temperatures favorable for barrier formation is necessary.

On freshly injured surfaces the rapidity of barrier formation may be more closely related to decay reduction than the extent to which the barriers are formed. Interest in providing conditions favorable for the formation of protective barriers on seed pieces before planting has recently been revived. The data show that even though tubers were stored several months at 40° F. barriers formed sufficiently to effectively reduce bacterial decay of cut surfaces, and that protective barriers may be an effective method of reducing seed piece decay. The possibility exists, however, that more effective use of protective barriers may be obtained by cutting seed pieces shortly after tubers are harvested, when the barriers develop more rapidly.

Summary

Eight varieties of potatoes were stored at 40° F. for various periods. Slices from these tubers shortly after harvest and after 3½, 5½ and 8 months were held in moist chambers at 70° for 1, 2, 3 or 4 days and then examined for the presence of suberin and wound periderm. Rather rapid formation of suberin and wound periderm formation occurred after all storage periods but the greatest development of both barriers usually took place shortly after harvest. Formation of these barriers decreased after 3½ months' storage and did not change appreciably with longer storage. Inoculation of the slices with *Erwinia atroseptica* after the slices had been held for different periods at 70° showed that bacterial decay and barrier formation were negatively correlated.

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NEWS AND REVIEWS

THE USE OF NORTH AMERICAN POTATO VARIETIES IN NEW ZEALAND[1]

R. G. ROBINSON[2]

Before referring to the performances of American potato varieties in New Zealand, it would be as well to give some brief particulars of New Zealand's potato production.

New Zealand's potato growing areas extend from Kaitaia in the North Island to Tuatapere in the South Island, nearly from sub-tropic to cool temperature conditions. Soil types vary considerably but the weather is much more variable. Certain districts, mainly near the coast are practically frost free throughout the year. Other districts have only a few months freedom from frosts. Rainfall ranges from 60 to 70 inches per year down to 27 to 30 inches. Summer droughts are met with fair regularly in parts of the South Island and occasionally in some northern areas. Wide variations in soil and climatic conditions require a wide range of varieties to suit the various conditions. Late blight infection is common in most humid areas and is likely to occur in any part of New Zealand.

New Zealand grows from 18,000 to 20,000 acres of potatoes each year, and of this area about 70 per cent is grown in the South Island. The Canterbury Plains produce the bulk of the South Island crop. These Plains range from 10 to 1200 feet above sea level and supply most of the seed potatoes for New Zealand's crop. The high altitude area produces seed for the lower areas of Canterbury and for other parts of New Zealand. Many North Island Districts need to secure fresh seed each year from the South Island as the spread of virus diseases is much greater in the north. Other areas can maintain seed stocks for two seasons, but there are very few districts in the North Island that can produce high class seed.

The Canterbury Plains have a climate suitable for seed production. The higher altitudes have cool temperatures and a rainfall of 38 to 40 inches, and virus carrying aphids are seldom present. The lower altitudes are more open and wind-swept and have a rainfall of 25 to 28 inches and there is a slight increase in the virus spread. The North Island climates are warm and humid with a rainfall of 32 to 56 inches. The aphid population is much greater under these conditions.

The Government Certification Scheme for potatoes was commenced in 1927, and has been the major instrument in raising the standard of seed potatoes in this country. In the 1957-58 season the area which passed the Certification Test was 5728 acres. This was made up of 22 varieties, the four leaders being:

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[1]Accepted for publication July 24, 1958.

[2]Member, Government Appointed Seed Potato Advisory Committee and Past Chairman, New Zealand Potato Board.

Variety	*Origin*	*Acres*
Aucklander Short Top (a strain of Suttons Supreme)	Great Britain	1551
Sebago	U.S.A.	923
Dakota Red*	U.S.A.	791
Ilam Hardy	New Zealand	549

*Also known as Red Skin in the USA and Clark Seedling in Canada.

American varieties which played a part in New Zealand's potato production up to 1934 consisted of: Dakota Red, Beauty of Hebron, Gold Coin, Early Rose and American Wonder.

The four last mentioned are now out of production.

The Dakota Red was introduced about 1906 and has found a permanent and valuable place in New Zealand production. It is grown mainly on the poorer land of the Canterbury Plains and resists drought and keeps very well. The area in certification in 1957-58 was 791 acres, 13.8 per cent of the total, which is an indication of its value.

Green Mountain, White Rose and *Irish Cobbler* came to New Zealand between 1935-40 but did not find favour with growers.

Katahdin, Chippewa and *Sebago*. These fine American potatoes were forwarded to the writer's firm between 1936-38 by the U. S. Department of Agriculture. They were widely tested in New Zealand with the following results:

The *Katahdin* appeared to do best in the North Island districts and seed for this area is produced in Canterbury. Katahdin has made headway steadily as the quality and appearance of the tubers are of the highest. The area planted to Katahdin will increase steadily in New Zealand, but it is more susceptible to blight in the North Island than Aucklander Short Top, Sebago, Ilam Hardy and Glen Ilam which are the main varieties grown commercially there.

On the Canterbury Plains the Katahdin does not produce heavy crops unless sheltered from our strong, dry, nor'west winds, which are most prevalent during mid-summer.

Chippewa was found to be better suited to the South Island districts and today is the most favored garden potato in that Island, although it prefers some shelter.

Sebago. This fine potato has proved a most valuable one in New Zealand and the area planted with this variety is steadily increasing. On the Canterbury Plains it stands up well against high winds, has marked drought resistance, and is an excellent marketing potato, if dug and handled carefully.

In the North Island the Sebago is the best blight resistant variety grown, and yields very well under most conditions. The quality is generally very good although not so consistent in this respect as Chippewa and Katahdin.

Below we listed the acreages of Sebago, Chippewa and Katahdin that passed the Government Certification Test for the last three seasons.

	1955-56	*1956-57*	*1957-58*
Sebago	476	670	923
Chippewa	229	211	327
Katahdin	134	132	167

Kennebec. The rapid advance in the area planted to this variety in the U.S.A. indicated that it might be suitable for New Zealand, so it was tested widely for a number of years and was found to be highly blight resistant with some drought resistance, with quite a good cropping capacity. However, its cooking quality was inconsistent, varying according to soil conditions and for this reason is not likely to be grown in New Zealand to any great extent.

Other American varieties that have been tested in New Zealand include Pontiac, Warba, Red Warba, Mohawk, Houma, Pawnee, Erie and Sequoia, but these varieties did not find a place in New Zealand for various reasons.

Later American varieties which were tried in New Zealand were Seneca, Ontario, Teton, Essex, Placid, Harford, Chenango, Cherokee, Ashworth, Snowdrift, Yampa, Canso and Keswick. Some of these varieties were bred with the use of the South American species and had marked scab resistance, others blight immunity, (to some strains) and Ashworth was frost resistant.

These potatoes were first tested in trial grounds in Canterbury and some performed well. Wider trials were then carried out in other parts of New Zealand and some were included in the Department of Agriculture trials at Levin, North Island, from one to three years.

In the final evaluation of these varieties, the main reasons for their failure was brown fleck, hollow heart, or lack of culinary quality, and in the case of Seneca and Ontario, their susceptibility to blight.

Cooking quality. The culinary quality of potatoes in New Zealand is of paramount importance and three varieties, namely, Chippewa, Katahdin and Suttons Short Top are the *Vade Mecum* by which all new varieties are judged. A new seedling variety must approach the standard of these varieties otherwise no matter how high its other qualities are, it has very little chance of becoming a major variety in New Zealand.

Summary

The four major U.S. varieties grown in New Zealand, namely, Chippewa, Katahdin, Sebago and Dakota Red occupy 38.5 per cent of New Zealand's potato area.

Three New Zealand varieties were crossed with the Chippewa potato and they cover about 12.8 per cent of New Zealand's potato area, judged by the Government certification figures. Potato varieties from the United States of America have played an important part in New Zealand production and the present varieties are likely to play a larger part in the future. Some of the newer American varieties, after careful and widespread testing, may be found suitable to New Zealand conditions.

Acknowledgments

The writer would like to express appreciation for assistance received from the U.S. Department of Agriculture (various sections), to individual officers of Agricultural Colleges and Experimental Stations, and especially to Dr. F. J. Stevenson for tubers of new varieties and much helpful advice over a long period. Mr. Kris P. Bemis has also been most helpful with information and advice on potato matters.

REPORT OF POTATO NUTRITION (FERTILIZATION) COMMITTEE

The remarkable increase in potato production per acre that has taken place during the past two decades can be attributed, quite properly, to a number of causes. Among these, improvement in the nutrition of the crop has been an important one. Reports show that the average yield of potatoes per acre over the 20-year period has more than doubled. This achievement, however, does not necessarily mean that all potato nutritional problems have been solved. On the contrary, specific nutritional problems are still important limiting factors in many of the potato-producing regions. Even though, in general, much progress has been made, a need still exists for nutritional studies within the framework of the larger body of scientific and technical information available. The members of the committee on nutrition feel that it may be worth while to call attention to some specific problems .

South

In southern potato-growing regions nutrition problems on light soils continue to be important. During wet seasons, potatoes on these soils often suffer from nutrient deficiency, first of nitrogen then potash and finally phosphorus. Magnesium deficiency on these lighter soils is also often a common occurrence that tends to limit yields in wet weather. The problem is not a simple one because it concerns not only plant food solubility but time of fertilizer application as well. This also involves the questions of side dressing and split fertilizer applications.

In general, information on rates of fertilizer application and sources of nitrogen, phosphoric acid, and potash is adequate but where intensive cultural methods are practiced, especially with irrigation, more information is needed on the use of organic materials.

Information on methods of fertilizer application is likewise adequate for normal purposes except where problems involving time of application are concerned. For these problems another look at the question of fertilizer placement may be required as it relates to particular growing conditions.

A new approach to the old problem of plant food ratios may also be required, The general tendency to increase the ratio of nitrogen and potash to phosphoric acid may eventually require an evaluation of new methods of fertilizer use involving split applications of separate ingredients patterned after those now used in Europe.

West

The most important problem in the west, and the one attracting the most attention at present, is the black spot or stem-end bruising problem. Although, so far, nutrition has not been proved a definite cause of this trouble, nevertheless the possible effects of nutrition as a contributing cause cannot be ruled out. Certain information has suggested that high levels of potash have reduced the trouble while high phosphorus has seemed to favor it. Further work undoubtedly will be needed to decide the place of nutrition, if any, in this problem.

Nutritional problems in the west, for the most part, center around

the use of nitrogen and it is here that a need also exists for more research. More information is needed, for example, on the effects of high nitrogen applications in solid and also in liquid and anhydrous forms. The effects of nitrogen on yield and quality of table stock and chipping quality are particularly important.

Other nutritional problems in the west are related to sandy soils. These soils confront the potato grower with special fertilizer application problems, especially where irrigation is used.. For example, when high rates of application are used would it be better to broadcast part of the fertilizer or to make supplemental applications rather than to use a single at-planting application? More specific information is needed on this problem and others peculiar to sandy soils .

East

One of the nutritional problems of increasing importance in the east stems from the use of excessive amounts of phosphorus and potash on soils already containing appreciable accumulations of these elements. Not only are the accumulated amounts of these elements concerned, but also their rates of availability in relation to the critical needs of the crop, especially during early growth. The whole problem is also related to the parallel economic problem of financial returns from high fertilizer rates which also need more attention.

More information on side dressing potatoes is also needed. The practice of placing fertilizer in bands at planting time has generally proved satisfactory but there is some evidence to show that in certain cases withholding one-half of the nitrogen for sidedressing may improve its efficiency.

The response of potato varieties to seed spacing, size of seedpiece, and rate of fertilizer application, seems to be of growing importance, especially of newly-named varieties.

The problem of pressure bruising still remains important in the east but, as elsewhere, it has not been definitely related to nutrition. The possibility that nutrition may be a contributing cause acts as a stimulus to further research on this important problem.

Canada

In Canada one of the important nutritional problems in potato production concerns the use of nitrogen, especially in relation to other farming practices. The nitrogen problem is always more critical where potatoes do not follow a grass-legume crop or where no manure is applied. The problem covers not only the use of nitrogen but also the manner of applying it. The question of applying part of the nitrogen as a side dressing is always important where large amounts of this element are used.

The need for further development of nutrient diagnostic techniques including soil and plant tissue testing is increasing. Calibration of such tests with known field responses holds great promise for a more effective fertilization of the potato crop. Specific information of this type is urgently needed also for the determination of nutritional relationships to quality in any areas.

Fundamental Research

This report would not be complete without some reference to the recent trend toward fundamental research that appears to be taking place. One significant event indicating the importance of this trend occurred recently when the U.S.D.A. announced the establishment of 11 exploratory laboratories. One of these which is to be concerned with fundamental problems in plant nutrition is being fully supplied with innovations in equipment and techniques. This trend in fundamental research, indeed, represents a significant step forward that forcasts much in the way of a better understanding of fundamental plant processes in the future. The eventual outcome of fundamental research, to be sure, cannot be predicted with certainty, but we can be sure that any new finding in plant nutrition forthcoming can certainly be expected to have a significant impact on potato nutritional practices. In this regard it is worth noting that changes occurring in these practices over the years nearly always have reflected the changes taking place in the manufacture of fertilizer. This illustrates the close relationship that can be expected to exist between research and development in the field of potato nutrition.

In this report your committee has attempted to point out some of the gaps in potato nutrition information where more research is needed. The list is not intended to be complete because the need for research in potato nutrition, as in all fields of crop production, is never static. Your committee is convinced that new findings emerging from fundamental research in plant nutrition will eventually have a definite impact on potato nutritional practices. If this occurs, more, rather than less experimental work will be required. This possibility and the certainty that greater production will be required to feed our rapidly growing population, combine to guarantee a growing need for research on potato nutrition in the years ahead.

Respectfully submitted:

Dr. Arthur Hawkins
Dr. O. A. Lorenz
Professor N. R. Richards
Dr. L. M. Ware
Dr. G. V. C. Houghland, *Chairman*

BLACK SPOT SYMPOSIUM SUMMARY[1]

R. L. SAWYER

Black spot of potatoes was first described over 50 years ago in Europe. It was first recognized in the United States in the 1930's, and has been a problem on Long Island since that time. More recently black spot has been recognized in all of the major potato producing areas in the United States and in some sections of Canada. It is considered one of the most important, if not the most important, physiological disorder in potato production at the present time.

A symposium on black spot was arranged by the American Potato Association at the 1958 meetings in Bloomington, Indiana. Research workers from the various potato areas presented the problem as it exists, the work being done, and recommendations to control black spot. The reports from these areas have been summarized by the author (2) in the following paragraphs.

All workers reporting were in agreement that the disorder being discussed was similar. This disorder termed "black spot" is a sub-surface black to grey discolored area occurring beneath the skin but generally not deeper than the cambial layer. The discolored area takes place at the spot of some previous surface bruise or pressure not serious enough to break the skin in any way.

BRITISH COLUMBIA — N. S. WRIGHT

Black spot (blue spotting) first occurred to an economic extent in British Columbia in 1956. In that year the disease developed in tubers grown on certain farms in the non-irrigated coastal area. In all cases the affected crops suffered from a shortage of moisture late in the growing season. In 1957 when growing conditions were normal the disease did not occur.

In a relatively small area in the southern interior of the province which is extremely dry and hence irrigation of potatoes is necessary each year, black spot was prevalent both in 1956 and 1957.

The Netted Gem which is the only major main crop variety grown in B. C. (74 per cent of the total acreage) is the only variety in which black spot has been found.

CALIFORNIA — JOHN W. OSWALD

Black spot has been of increasing significance since 1950 in the Santa Maria area on the Russet Burbank. More recently it has been a problem in Kern County. In 1957-1958 it was a serious problem with White Rose variety.

Fertilizer tests indicate that high potassium fertilization significantly reduced black spot but did not give commercial control. High potassium fertilization delayed the outbreak of black spot. Potatoes under 70 to 75 days old were not susceptible to black spot. After this period, susceptibility markedly increased following the removal of irrigation water prior to digging, but fell off as the potatoes remained in the soil over two weeks.

[1]Accepted for publication December 1, 1958.

[2]Associate Professor, Vegetable Crops, Cornell University, Riverhead, Long Island, N. Y.

There was no correlation between specific gravity and either black spot development or potassium levels in the plant.

IDAHO — WALTER C. SPARKS

Black spot in Idaho has been considered synonymous with bruising and research has been pointed to reducing the bruising which occurs during the harvesting and handling operations. Rubberizing all equipment, slowing down equipment and bringing the temperature of tubers up to 40-45° before they are handled out of storage, are important factors. Growers are recommended to stop irrigation the last week in August, or not later than the first week in September to allow potatoes to completely mature. Irrigate a few days before harvesting to moisten clods and give a nice, friable, mellow, soil for the digging operation. By following this procedure, bruising is kept to a minimum and black spot seldom becomes an important problem.

MAINE — HARVEY V. TOKO

Black spot in Maine is associated with pressure bruises which develop as the storage period progresses and tubers become less turgid. As the storage period increases, the incidence of black spot increases. As high as 25 to 40 per cent of tubers showed black spot by June in an experimental lot during the 1956-1957 storage season. In the 1957-1958 storage season black spot caused losses ranging from 1,200 bushels to as high as 54,000 bushels per individual grower and affected the varieties Katahdin, Ontario and Kennebec. Potatoes stored in pallet boxes did not show black spot until after they had been removed from boxes and subjected to pressure for at least three weeks.

NEW YORK — RICHARD L. SAWYER

Black spot is an important problem on Long Island every year although it varies considerably in intensity. It is encountered to a much lesser degree in other sections of the state. It does not usually occur until well into the storage season, sometime in December, but it may be encountered in the harvesting period. Keeping bruising to a minimum will help prevent the disorder, but will not give satisfactory control.

Black spot has been a major research project for almost 20 years. Some of the factors taken into consideration have been all of the major elements and most of those considered as minor, planting dates, harvest date, soil temperatures, irrigation, seed sources, varieties, insect vectors, rate of ventilation in storage, moisture content of ventilating air ,tuber firmness, cell turgidity, and sprout inhibitors. Considerable laboratory work has been conducted to determine what chemical reaction takes place.

In the light of recent work, a common physical denominator as been found which seems to fit together the many factors which have been found to influence black spot. This denominator is cell firmness and turgor. Black spot can be produced in the laboratory in discs from non-susceptible tubers by removing some water from the potato cells. By allowing water to return to these cells, the discs become non-susceptible again. The tuber must get to a certain point of physical softness before the chemical reaction will take place. Anything which influences cell turgor or tuber firmness such as planting dates, potash fertilization, lenticel structure of varieties,

ventilating air in storage and length of storage season will influence black spot. Any factor in potato production from planting to the table which gives a firm skin and firm cell structure and decreases the loss of moisture from the tuber, aids in the control of black spot.

WASHINGTON — W. G. HOYMAN

Black spot is a disorder of serious economic importance in Washington. This disease is encountered directly from the field and tubers do not have to go through a storage period for the disorder to occur. Dr. Robert Kunkel is working on this problem, emphasizing moisture relationships in his approach.

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What they haven't found out, however, is the best way to prevent this shrinkage.

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Humidity is one of the key factors affecting the firmness of stored potatoes. If it can be regulated so that just the right amount of water vapor moves with the ventilating air in and around the potatoes, shrinkage can be held down.

Humidifying may be accomplished in several ways. Air can be blown across a wet surface, thus moving moisture-filled air into the storage room. Air at high velocity may be mixed with water particles that are finely dispersed by centrifugal force. Or, a pneumatic spraying system installed.

Each of these three methods worked well in AMS tests conducted both in commercial storages and research facilities.

Studies at the Long Island Vegetable Research Farm of Cornell University have amplified these findings. Experiments here proved conclusively that the introduction of water vapor in the intake ventilating air of potato storages increases firmness and decreases shrinkage.

These tests also pointed up several other rather pertinent facts:

1. The rate of air flow should not exceed 0.8 cubic feet per minute per hundredweight. At higher rates, shrinkage will increase — unless, of course, more water is also added.

2. Small differences in hardness between similar lots of potatoes point out significant differences in weight loss by evaporation of water from the tissues.

3. On Long Island, the optimum rate for adding water is approximately 1 pound for each 10,000 cubic feet of air.

4. Moisture vaporized directly into the storage space rather than through the ventilation system is not effective in reducing shrinkage caused by loss of water in transpiration.

—Reprinted from "Agricultural Marketing", September, 1958

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Why potato soils need magnesium

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